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HEAT TREATMENT FROM THE PRODUCTION ENGINEER'S STANDPOINT.

Paper presented to the Institution, Birmingham Section, 10th April, 1929, by L. D. Creedy.

(Read on the same occasion as the Paper by Dr. Walter, given in previous issue).

IN discussing heat-treatment as it concerns the Production Engineer, the starting-point is, in this, as in all other manufacturing operations, the necessity for uninterrupted supplies of parts for subsequent assembly or use. Before discussing the practice of heat-treatment, it may be of advantage to examine how the work of the heat-treatment shops affects, and is related to, other sections of production work. Heat-treatment is a link in the chain of operations from the raw material to the finished article. It follows, therefore, that the work of the heat-treatment department affects the chain of operations in two directions; that is, any hold-up in heat-treatment causes an immediate accumulation of output from the preceding operation, with possibly a temporary suspension of operations until normal conditions are once more reached. On the other hand, at the outlet side of the heat-treatment

operation, any hold-up in heat-treatment produces, as it were, a condition of starvation in the following operation, due to an interrupted flow of work. This again may lead to a temporary suspension of operations. Of course, such an interruption makes its effect felt throughout the whole chain of manufacturing operations.

The same thing can be said of any sort of interruption in other operations besides heat-treatment, but I think it will be agreed that the quality of a heat-treated product is of the very first importance.

Inefficiency or failure of a finished product may be traced to inaccuracies in machining, grinding, setting and so on; this is a fairly easy thing to remedy. Also, machining and like operations can be closely controlled by inspection and viewing. If necessary each individual component can be so examined.

The physical condition of a heat-treated component is, however, a much less tangible thing to control. It is obviously impossible to test or examine with absolute certainty, the physical condition of every component, as this condition is a function of the internal condition of the material; that is, such things as grain size, freedom from inclusions and dirt, molecular arrangements of the various constituents. All play their part in determining the ultimate success or failure of a finished part. The nearest approach to individual inspection of heat-treated parts is the testing to destruction of a proportion of the total parts treated, and in some cases the individual hardness testing of all parts.

I hope I have indicated clearly that the smooth working of a continuous flow of perfectly heat-treated work depends on the efficiency of the actual heat-treatment operation.

Of course, it follows that the inspection of heat-treated work is of the greatest importance, as, it seems to me, such inspection is largely a matter of deduction. An inspector of heat-treated material must satisfy himself that not only are the actual parts tested correct to specifications, but that they are representative of the true condition of the bulk lots from which they are taken. This means that the inspector must be satisfied that the heat-treatment operation has been done with efficient plant, efficient workmen, and accurate temperature control.

The first thing of importance to ensure smooth working of manufacture where heat-treatment is involved is, of course, the correct choice of materials. I think it is true that under modern methods of manufacture, the most important feature in the correct choice of materials is the physical strength which is necessary in the finished article. The designer, therefore, is responsible in the first instance for the determination of the stresses which any component or part is capable of withstanding. It then remains for the correct choice of materials to be made, to give that requisite strength. Dealing more particularly with steels, the choice of modern steels

is a more scientific job than ever it was. The tendency of modern design is to reduce weight without sacrificing strength. The purchasing of raw material, therefore, should be done not only with an eye to price, but with regard to such a quality as will produce smooth working and freedom from troubles which may be encountered by using cheaper and therefore inferior material. In fact, it is easy to see that by saving so much per ton on cheap material, this saving may be converted into a very much greater loss if trouble occurs with all its attendant loss in production.

It therefore follows that the smooth working of a continuous flow of perfectly heat-treated work depends, firstly, on the correct choice and purchase of good materials ; secondly, on the efficiency of the actual heat-treatment operation, and finally, on the intelligent inspection of heat-treated work.

I propose now to deal with the practical side of heat-treatment, indicating, if I can, points to be observed in obtaining that smooth working and freedom from troubles, so necessary to the peace of mind of the production engineer. The first necessity is that the flow of work to the heat-treatment shops should be regulated according to the capacity of the shops to deal with work requiring different treatment temperatures. To illustrate this point, let us imagine a heat-treatment shop dealing with drop forgings, some of which require hardening and tempering, some normalising and some annealing. The shop is equipped with five furnaces of the same size. Two of these are intended for normalising and hardening, and three for final tempering of hardened forgings. One can see that an irregular flow of suitable work can quickly produce confusion in the heat-treatment shop. For instance, an abnormal flow of forgings for normalising only, can hold up work requiring hardening and tempering, and as three furnaces only are available for the higher temperature normalising, the remaining two tempering furnaces are in a state of temporary stagnation. In order to obtain a regular output of heat-treated work from a plant such as this, it is necessary first of all to reserve furnaces for (*a*) Normalising, (*b*) Hardening, (*c*) Tempering. The throughput per furnace for a definite period should then be estimated as accurately as possible, and the flow of work for the different heat-treatment operations regulated accordingly.

The steels most commonly employed in the manufacture of drop forgings are straight carbon, nickel and nickel chromium steels. Steel conforming to British Engineering Standards Specification S.14 is a low carbon steel which is used for drop forged parts which have to be case-hardened. Steel conforming to S.6 in a medium carbon, which is largely used for parts which, in the normalised state, must have a minimum ultimate tensile strength of 35 tons per square inch.

Steel complying with Specification S.9 is a 3 per cent. nickel with

about .30 per cent. carbon, which must give a minimum ultimate strength of 45 tons per square inch. Cases have come to my notice where this steel has been confused with 3 per cent. nickel with about .15 per cent. carbon, a case-hardening steel, with disastrous results.

Steel complying with Specification 3.S.11 is a nickel chrome alloy steel, which must have, in the heat-treated condition, an ultimate tensile strength between 55 and 65 tons per square inch.

The points to watch in the normalising of drop forgings can be briefly stated as follows.

When charging the furnace for heating, the parts should be loaded in a way which will produce least warping or distortion. The load should on no account be removed from the furnace until thorough soaking at the required temperature has been attained.

The object of normalising is to remove ill effects of forging, and as the term indicates, to bring the steel back to the normal condition, by heating through the critical range and cooling freely in air. To get this result, perfectly, the two essentials are thorough heating at the correct temperature, and the free air cooling. It is therefore necessary, when free air cooling, that the parts should be separated, that is, that work should not be allowed to cool in a bulk, as this produces inequality in the rate of cooling of the parts.

The hardening of drop forgings is done in water or oil, usually oil. In quenching work, attention should again be given to the best way of quenching to produce minimum distortion. When quenching, the work must have movement in the quenching medium. It is not sufficient merely to dump hot work into oil or water and let it cool in a bulk. This will inevitably lead to unequal rates of cooling and consequent patchiness. Drop forgings heated in pans for hardening should be quenched into a moving basket, so that the maximum volume of oil or water can come into contact with the work, and thus facilitate the rapid cooling necessary.

Tempering Drop Forgings.

In passing, I would mention the necessity for efficient cooling of the quenching medium. The tempering of drop forgings is, in my judgment, the most important operation of this class of heat-treatment. It must be remembered that the tempering temperature determines the final physical strength of the parts treated. Not only must particular care be taken on this account, but also because efficient tempering is the more difficult of the two operations. It is well known that an even low temperature is more difficult to obtain than an even high temperature. When we remember that an error of only 10° C. may, with some steels, be sufficient to produce a physical condition just outside specification, the importance of the tempering operation will be apparent. In this connection, excellent results have been obtained by tempering drop forgings with a copper plate on the floor of the furnace. In tempering drop

forgings, the soaking time should be prolonged. This is especially necessary in the case of the high tensile alloy steels; indeed, it has been found that soaking for two hours or more has been necessary to obtain an even degree of hardness throughout the mass.

Testing in the Hardening Shop.

It is desirable that some form of hardness testing should be available in the hardening shops, as distinct from the inspection department. This is necessary, in order that the degree of hardness required can be obtained during the actual heat-treatment operation; that is, it is not always sufficient to work only to the actual temperatures specified, regardless of section and mass of the parts being treated, but a Brinell or similar hardness testing machine should be available to test samples of a load being heated before unloading the bulk of parts from the furnace. Sometimes it is necessary that test bars for physical testing should be heat-treated with a required number of forgings. It is obviously necessary that the test bars should be heated with the batch in such a way that they are representative of the batch. In other words, it is useless testing a test piece for physical properties, if the heat-treatment has been done in a furnace which is in poor condition as regards evenness of temperature.

The efficient heat-treatment of drop forgings is largely dependent on the actual forging operation. It is possible to forge steel so badly that no amount of heat-treatment will put it right. If the forging is done at too low a temperature, severe stresses in the steel may be produced, which lead to distortion when heat-treated. On the other hand, the forging temperature can be so high that burning and excessively large grain size are produced, which cannot possibly be rectified by heat-treatment.

Case-hardening.

This operation, perhaps more than any other heat-treatment work, is applied to the greatest number of production parts. Case-hardening, of course, is the producing of a high carbon case on a low carbon steel. By using a low carbon steel and case-hardening, the machining costs are low and production more rapid, owing to the lower first cost of the steel and ease of machining. Perhaps the most important advantage of case-hardening, however, is the ability to produce a hard wearing surface which resists abrasion in conjunction with a core which is more or less ductile, and possesses a fairly high impact value. This condition is most desirable in parts which under work are subjected to bending or impact stresses, and at the same time are subjected to a wearing or abrasive action as in bearings, gears, etc. Efficient case-hardening, therefore, demands these two important conditions, that is, a hard case and a core with a high impact value combined with the highest possible elastic limit.

The conversion of the low carbon surface to high carbon is, of course, due to the absorption of carbon from gases which are evolved, when heated, from carbonaceous materials or compounds. The rate of penetration is a function of the carburising temperature; that is, penetration is slowest at, say, 750° C., and increasingly rapid up to, say, 1000° C. This point will be referred to later.

The operation of cementing consists of packing the machined parts in contact with a gas evolving material, in a sealed box, and heating for a period and at a temperature which are dependent on the depth of case required.

This is often regarded as quite a simple operation, but I would like to suggest a few practical points which, in my experience, require careful attention, to obtain the best results. The first important requirement is an efficient carburising compound The requirements here are that the compound should be of uniform mixture so that inequalities in depths of case may be absent ; that the rate of penetration of carbon should be neither too slow, nor too rapid ; that the shrinkage of the compound should not be excessive, as, if this is so, there is a danger of the compound falling below the level of the top layer of work during carburising. Further, the compound should be capable of some degree of regeneration, so that by mixing with a suitable proportion of new material, the compound may be of further use. The question of the rate of penetration is important when deciding on a suitable compound. It does not follow that the compound which produces the most rapid penetration is the best one to use when first-class quality of case-hardening is desired. A compound may produce a very deep case in a very short time, but if the carbon content of the case be estimated, it may be found to be only .6 or .7 per cent. carbon.

It is generally accepted that the most suitable case carbon content, for hardness and good wearing properties, is at or above the euctectoid content of .89 per cent. carbon. Case carbon contents of over 1.0 per cent. are not desirable, as there is here a distinct danger of exfoliation of flaking, due to the free cementite so produced. The method of packing work in compound is of considerable importance. Attention must be paid to the possibility of warping during the prolonged soaking at a high temperature in carburising. Work should be packed in positions which allow an equal contact of the work with the carburising gases which are evolved.

The size of the carburising pots in relation to the size of work is of importance. For example, if a large quantity of *small* parts are carburised in an excessively large pot, unequal penetration of the parts will inevitably occur, due to the fact that heat absorption in carburising commences at the outside of the pot. In other words, the first parts to reach the carburising temperature are those nearest the outside of the pot, and the last parts to do so are those in the centre. This means, of course, that the carburising periods are

different throughout the bulk of parts being treated, and consequently different depths of case are obtained.

The sealing of the pots during carburising requires attention. A more equal contact of work with carburising gases is obtained if the gases are under pressure, that is, if the pots are effectively sealed. The result of badly sealing a pot is to produce an unequal flow of gases around the work due to unequal pressures inside the pot. Cases have come to my notice where no sealing whatever is used. While this practice is not to be recommended, it has the virtue of giving an equal pressure inside the pot, as compared with a pot which is supposed to be sealed, but which is not. The sealing of pots is much simplified by using nickel chrome and special alloy pots which have recently come into favour. These are cast with a rebated lid which engages with a corresponding rebate on the box, thus allowing a close fitting lid with the minimum of luting.

I have referred to the question of depth of penetration being governed by the carburising temperature. This fact can be used, if applied judiciously, in case-hardening parts of a large variety of sections. For instance, if it is desired to produce a very thin case on very small articles, the low carburising temperature of about 750-780° C. can be used. Very successful work has been done along these lines by intimately mixing the small parts to be lightly cased with a finely graded compound, loading into tubular pots, soaking at the low temperature for short periods, and quenching directly from carburising. This method, of course, is only applicable to parts which require very shallow cases.

In the case of parts requiring a normal depth of penetration of $\frac{1}{32}$-in. and over, the carburising temperature of 900-950° C. is most commonly used. If a very deep case, say, $\frac{1}{8}$-in. and over, is required, temperatures up to 1000° C. can be made use of. The use of very high carburising temperatures naturally means a heavier cost due to increased fuel consumption, heavier pot costs, etc. The question whether the heavier cost involved can be justified by an increased production is a question for individual concerns to decide for themselves under their own conditions.

The higher carburising temperatures produce in the steel an increase of grain size and brittleness which has to be rectified by subsequent re-heating. After carburising, not only is the core of the steel, due to the long soaking, in a brittle condition, but the high carbon case is also very coarse grained. The condition of the case is very similar to a cast tool steel which has been overheated to 900-960° C. These two conditions of brittleness mean, therefore, that two different re-treatments must be applied to bring the steel back to a usable condition. In effect, there are two entirely different steels in a carburised job, a low carbon core where no cementation has taken place, and a high carbon steel which is the case.

To restore the low carbon core to its original condition, it is necessary to re-heat to a temperature in excess of the carburising temperature, and quench. In other words, the decalescent point of the low carbon core is high, say, about 880° C., and the re-heating temperature must exceed this point. The case, however, is now a high carbon steel, and as it is well known that, as the carbon content increases, the decalescent point is lowered, the quenching temperature to restore the case is also lower.

The re-heating treatments therefore are :—

900° C. or over, quench, to restore the overheated case.

750-780° C., quench, to refine the overheated case.

The re-heating temperature of 750-780° C. is well below the critical temperature of the core, so that this second re-heat does not upset the refining of the core already obtained in the first quench. Indeed, within limits, this second re-heat has a tempering effect on the core. It has been observed, however, that the refined core tends to revert to the brittle condition if the case refining temperature is higher than 800° C.

The faults to be guarded against in the production of case-hardened parts, are brittle core and patchy hardness. The latter fault can almost always be traced to de-carbonising which occurs principally during the high temperature re-heat for core refinement. It is generally agreed that the higher the carbon content of a steel, the more readily will it de-carbonise. It is therefore essential, in order to obtain a surface which is not de-carbonised, that the re-heating furnace atmosphere should be as free from oxygen as possible. This condition is readily obtained in a modern gas furnace, with suitable adjustment.

Before leaving the subject of case-hardening, I would mention that the question of core strength and mild case-hardening steel is a wide field for discussion. The most generally accepted idea regarding core strength is that, to put it colloquially, "it should bend before it breaks." This condition has much to recommend it, principally the safety factor which is associated with it; but I would indicate that there is an increasing tendency to dispute the soft core idea, on the grounds that a soft core possesses a low fatigue resistance as compared with a higher tensile core. It is maintained that the notched impact value of the core can safely be reduced, the tensile strength can be increased, with an increase in fatigue resistance.

The Treatment of Press Tools.

A branch of heat-treatment work which concerns the production engineer in different ways from those already dealt with, is the hardening and tempering of press tools. So far, we have considered the heat-treatment of actual manufactured parts. The heat-treatment of tools for making those parts is of very great

importance. The steady production of work from press tools is again dependent on freedom from interruption due to tool failure. If we start at the point that all press tools have a definite limit of usefulness, it naturally follows that the more efficient the heat-treatment, the longer will be the life and production from the tools. If the cash value of press tools is estimated on the basis of their production, it would seem that any expenditure on plant and apparatus for carrying out the initial hardening and tempering could easily be justified. I am afraid that often the hardening operation is regarded as a necessary evil and is done in a haphazard way with little regard for the ultimate production life of the tools. How often one finds expensive tools which have taken days, perhaps weeks, to prepare, being heated for hardening on a blacksmith's hearth, with little idea of correct temperatures and certainly no temperature control. It is therefore necessary that efficient hardening furnaces, with accurate temperature control should be used, to get the best results. Further, some definite means of testing for hardness should be available. A system could be organised in which the production from every press tool could be recorded. If, also, a complete record were kept of the exact treatment given to every tool, together with the hardness test figure, data could be collected on which further treatment could be based, in order to get still better production. For instance, if a press die is found to be rather soft, requiring frequent re-grinding, with attendant loss of time, if a record of the hardening treatment and hardness of that particular die is available, the subsequent treatment of similar dies doing the same work could be modified to give greater hardness, as desired. The same would apply to dies which were found to be too hard. By some such system, combined, as always, with correct selection of steel, definite bases could be determined to get the longest possible life from all tools in use. A checking system such as this would no doubt appear costly, but I am convinced that in time, the expenditure would be amply repaid by the elimination of interruptions in production, with the attendant heavy costs in stand by time, re-fettling or making new tools, etc.

Probably no branch of die hardening requires more accurate control of heat-treatment and hardness records than hot brass dies. The erratic behaviour of hot brass dies is notorious. This, I think, is largely due to neglect in establishing definite standards of hardness and heat-treatment for different classes of stampings, and carefully reproducing the same standards on new dies. The widely different sections of hot brass stampings make it necessary that most careful consideration should be given to the requisite heat-treatment and hardness required for any particular section of stamping. It is by no means sufficient to apply the heat-treatment given by the steel makers irrespective of the section of the stamping. For instance, a die for a deep stamping will be subjected to a more

or less severe bursting strain. It is obvious that in this case, the die will require the greatest degree of toughness combined with good resistance to wear. This die, therefore, would require to have a lesser degree of hardness than a more straightforward section with little or no bursting strain.

Regarding press tools for cutting and forming sheet metal, the most commonly used steels are plain carbon steels and steel faced iron on composite steel. This branch of hardening has its own particular problems, chief of which are cracking and distortion in hardening. This, in essence, is caused by expansion and contraction, which occur in the steel during the heating and cooling. The hardening of steel is due to conversion of the separate constituents of Pearlite into Martensite, which change occurs at a critical temperature. If by means of suitable quenching the reversion from the Martensitic to the Pearlitic or normal state is arrested, the carbides are retained in solution, the steel remains in a hard condition. Unfortunately, however, this change into Martensite is accompanied by an increase in volume, more particularly in the case of straight carbon steels. It is this increase in volume which is so productive of cracking and warping in hardening. In heating, an expansion occurs until the temperature reaches a critical range, at which point a sudden contraction will occur, and persist until a further increase in temperature produces a normal rate of expansion again. Bearing this in mind, we can appreciate the value of preheating tools before transferring to the hardening furnace, or heating very slowly to the hardening temperature. In other words, if the volume changes which occur on heating are only allowed to take place very slowly and uniformly, there is a far greater chance of eliminating cracking and distortion, particularly the latter. The value of slow heating is particularly apparent in the case of tools which have delicate and variable sections. Naturally, if the volume change in heating of a thin section takes place viciously and an adjoining heavier section relatively slowly, something has got to happen. Uneven and local heating will inevitably produce this state of things, and a culprit in this matter is our old friend, the blacksmith's hearth. It is absolutely essential for the best results, that furnace temperature should be dead even, and that heating should be slow and regular.

The volume changes in steel, referred to, during heating, take place in the reverse direction in cooling. As the steel cools through the critical range, a spontaneous evolution of heat occurs. The more rapidly a steel is quenched, the more complete is the conversion into Martensite, and the greater hardness is obtained. Also, the greater is the risk of cracking, particularly in the case of thin sections. Where the section of a tool is variable, having heavy and light sections in the same body, there occurs in quenching

a conglomeration of volume changes which impose severe stresses on the steel. The light sections, cooling rapidly, may be expanding at the same time as an adjacent heavy section is contracting, and *vice-versa*. To complicate matters, we have a very limited control over those movements. At best, all that can be done is to quench, in such a way that all sections cool as evenly as possible. In cases of extreme delicacy, slower quenching methods may be adopted. By doing this, the conversion into Martensite is less complete, and less hardness is obtained. At the same time the volume changes in cooling, already referred to, take place more slowly, and this gives an added factor of safety. In these cases, oil quenching may be resorted to.

I think it will be agreed, therefore, that the complicated behaviour of plain carbon steels in heat-treatment are such as to make this class of work most hazardous. It means that the section of each tool must be considered, and hardening methods determined accordingly.

A material which is extensively used for press tools is cast steel with a backing of iron, or what is commonly called half-and-half. The claim for this material is that the iron backing exercises a stabilising effect on the steel, and reduces the risk of cracking. This is undoubtedly true, but a drawback often encountered is that a press die made in this combination has a tendency to distort into a convex face when hardened. If the distortion is not too bad, and the dimensions of the cutting portions are not altered too much, the soft iron backing can be planed off flat, and a very useful shear produced on the face. If the distortion is too bad, however, annealing and setting are necessary.

I think that the distortion associated with steel-faced iron is principally due to the proportion of steel and iron being "half-and-half." If the proportion were two-thirds iron and one-third steel, the expansion of the steel face would be less, and the strength and stabilising effect of the iron backing would be increased, and there would be less risk of distortion in hardening.

A class of steels for press tools, which has developed of recent years, is that of alloy tool steels. These consist principally of chromium alloys. These steels are of special utility in the case of long-production work. They possess great density, and when correctly heat-treated, have a long life and production without fettling. These steels, mostly, require oil hardening or air hardening, and thus have the advantage of safety in heat-treatment. Also, the presence of chromium induces a more uniform hardening effect throughout the whole section, thus reducing the sectional strains met with in hardening plain carbon steels. The main disadvantages of these alloy steels are, heavier first cost, and, owing to their great density, the increased difficulty in working up to shape.

These disadvantages are more than compensated for by the longer life and increased production obtained.

Powder Moulding Dies.

An industry which has developed extensively is that of powder moulding for Bakelite and similar productions. This class of work has called for a new set of conditions in the matter of moulding dies. Broadly, the operation of moulding consists of the fusion between heated moulds, of certain powders which, when solidified, remain in the shape of the moulds. In the early days of the industry, the moulds were largely made of mild steel case-hardened. It was found that these mild steel dies produced discolouration of the moulded product. Extensive experimental work by the manufacturers eventually brought them to use moulds made from some form of chromium steels.

The position to-day seems to be that for long production contracts where a heavy first cost for moulds is justified, the chromium alloy steels are used. In the case of short production work, mild steel moulds, chromium plated after case-hardening, are used. The heat-treatment of these moulds demands the utmost care, as they are in a highly finished condition, and must remain free from blemish after heat-treatment. They must be absolutely free from scale, and the microscopic pitting which so readily occurs with highly finished surfaces. The chromium alloy steels meet these demands satisfactorily, as they do not oxidise or pit very readily during heat-treatment, apparently on account of the chromium content, and their great density.

The heating of moulds must be carried out in a non-oxidising furnace atmosphere; preferably, the moulds should be packed in inert charcoal or other carbonaceous substance. Discrimination should be used in the choice of this material. A new raw charcoal, for instance, has a tendency to give rise to an evolution of heat which may result in the work exceeding the furnace temperature, and damage the moulds by local overheating; this packing material, therefore, must be thoroughly fired and dead. A still better way of heating moulds for hardening is in an atmosphere of coal gas. This method is available in an excellent form in the Walter-Palser gas sealed furnace.

Annealing.

Annealing is a branch of heat-treatment which is of interest to the production engineer. This is usually associated with some branch of machine tool or press work. Annealing is usually interpreted in terms of softness, and, as such is of interest to machine tool and presswork departments where the degree of softness has an important influence on production. Imperfect annealing may lead to difficulty in machining. This may occur not only through annealed parts being too hard, but also through being too soft and

luggy. In the case of the annealing of pressings between draws the principal requirement is softness only.

In annealing, the same fundamental rules apply as in all other heat-treatment work. These are evenness of heating and accurate temperature control. If parts for subsequent machining are unevenly heated there must be a difference in the machining time allowed for each part, on account of the different degrees of machineability encountered. In press work, irregular heating may lead to splitting of the pressing or jamming in the press.

The annealing of pressings between draws is worthy of the closest attention. The heating for this work is often carried out at too high a temperature. Of course, the object of the treatment is to remove strains imposed on the steel in the drawing operation, and leave the pressings in a fit condition for further work. In the case of ordinary mild steel presswork, this condition can often be obtained by annealing at temperatures around 700° C. An added advantage of keeping this temperature as low as possible when open furnace annealing, is that the oxidation of the surface is less. As is well known, an oxidised or dirty surface has a wearing action on the press tools. For this reason, pressings are often close annealed, that is, in an atmosphere closed from the harmful action of oxygen.

The most commonly used form of close annealing is that of packing and heating in closed containers or boxes. Gas furnaces of the conveyor type have been developed for heating pressings on a continuous chain system in an atmosphere of coal gas or oil vapour.

The use of molten salt furnaces for many classes of heat-treatment work is steadily developing. This method of heating has much to recommend it, principally, evenness of heating, and cleanliness of hardened surfaces. The latter condition is particularly applicable to highly finished work such as moulds, gauges, etc. I would repeat the necessity of pre-heating work before immersion in the salt hardening bath for the reasons previously mentioned. The rate of heating is very rapid in molten salt, owing to the work being in direct contact at all points with molten heat. Unless pre-heating is resorted to, the volume changes which occur when heating steel, take place very rapidly. Pre-heating in a molten salt at a temperature of, say, 100° C lower than the hardening bath, will therefore be found an advantage.

The future development of steels is all in the direction of alloys, and in fact, this applies to all metals used in manufacturing processes. With this development, heat-treatment is becoming increasingly important. Advances which are made in the manufacture of metals and their alloys, must naturally be accompanied by continued improvements in furnace design, and in these advances, the gas heated furnace will continue to hold an honourable position.

Whatever progress is made, however, the main essentials of

good heat-treatment will remain. Heat-treatment, a thousand years hence, as now, will demand efficient plant for the application of heat, accurate temperature control, and a scientific understanding of the practice and reasons for heat-treatment.

Discussion.

MR. J. A. HANNAY, President of the Birmingham Section, who occupied the chair, said that, although the hour was late, he would hold the meeting for a short discussion on the two Papers to which they had listened.

MR. LOBLEY expressed surprise that no mention had been made of the electric furnace, particularly as photographs of gas furnaces had been shown in two works where electric furnaces were also installed. In one of these works the gas furnace was used at a particularly high temperature and was installed at a time when it was thought that an electric furnace could not efficiently do that work. In the other case the installation of a modern gas furnace was shown carburising, and in the same factory an electric furnace was doing the work at two-thirds of the cost.

MR. W. G. GROOCOCK said it had been very interesting for production engineers to listen to Papers such as they had heard that night from two lecturers who were evidently masters of their subject. Although Dr. Walter had not been quite so lenient to the electrical side as might have been the case, he had dealt fairly with the subject. On two visits to the United States he had had an opportunity of seeing a number of furnaces similar to those dealt with that evening and they had left him wondering why there was not the same quantity of work to put through in this country. While dealing with a similar problem we were only doing so in ones and twos, whereas Americans dealt in thousands and could afford to scrap in thousands before they attained their results. We in this country seemingly could not afford to scrap anything.

MR. H. C. ARMITAGE said that there was a great deal of experimenting going on with automatic furnaces. From the Papers that evening it might be thought that they were more fully developed than appeared to be the case. Experience did not seem to bear out the idea that they were anywhere near perfection. He would be glad if Dr. Walter would tell them what sort of carbonising material was used in the small rotary case hardening furnaces. He would also like to know Dr. Walter's opinion on copper-plating and painting.

DR. WALTER, answering Mr. Lobley, said he did not deal with the electric furnace for the reason that he had not sufficient information about it, and he had wished to confine himself to matters on which he would be in a position to give full details, if required. He quite agreed that great strides had recently been made. At the same time he could hardly accept the view that electric furnaces

could be operated at the same price as gas. He certainly had no figures which indicated that electric furnaces could be operated at two-thirds the price of gas. He did not agree with Mr. Lobley that whatever was done with a gas furnace could be done with an electric furnace and with added advantage. One of the great difficulties with an electric furnace was in getting a reducing atmosphere. It seemed that if one employs an electric furnace one must put in a gas seal. While he had not seen that done on a large scale, he thought it was an important point on which the gas furnace scored heavily over every other type. They could control atmosphere in the furnace over a very wide range. That was absolutely essential, and he felt that in that respect the gas furnace would always have a pull over the electric furnace.

With regard to rotary furnaces, in the majority of cases they employed nickel chrome containers, and the work was caused to rotate—or, rather to rumble—in those containers with an ordinary carbonising material. He believed there was a big saving in carburising material for the reason that it was completely used; moreover, a very uniform carburising atmosphere was produced within the carburising chamber. As to the advantage of copper-plating compared with painting, he could only say that his own opinion was that there was only one way of stopping off, and that was copper-plating, in spite of the fact that it was expensive and difficult. Some very useful work could be done by painting, but if one wished to be certain in stopping material after case hardening, his view was that a perfectly adherent, thin deposit of copper was essential and was the only real way to prevent cementation. Perhaps the better way, where it was possible, was to increase the section of the point where the stop off was required and turn off the cemented layer prior to quenching. But that could not always be done, though it was the best method of all. There were some excellent paints on the market. At the same time, there was no doubt that with properly copper-plated sections the effect was very satisfactory.

A vote of thanks to Dr. Walter and Mr. Creedy was adopted with acclamation.

FACTORY REORGANISATION.

Paper presented to the London Section, 24th April, 1929, by H. E. Taylor, M.I.Mech.E., M.I.A.E.

IT is fairly well-known that all human activities successfully applied in a given direction will produce results which will expand and grow until they reach a zenith and will then fall away again. This fact applies to the development of the energies of individuals, business corporations and nations, which must all commence, ascend, wane and finally fall. Nevertheless, the world as an entity goes forward and improves, which is evolution, for, as one nation, business, etc., recedes, others come forward and take the lead. The rapidity of growth, the length of time the business is successful and the time to which the final fall can be postponed depend on many things, some natural, over which man has little control, but mostly man-created and therefore controllable.

There is no fundamental reason why this rise and fall should take place and it is theoretically possible (could all human efforts be co-ordinated) to smooth out the peaks and hollows in the graph of human progress. Undoubtedly the trend of evolution is in this direction, but at present competition is necessary and the graph of advancement will be serrated, the most virile and more intellectually-endowed taking the lead and profiting by the example of the fallen.

The association of the foregoing with engineering will be illustrated by touching lightly on the position of the automobile industry in Europe and illustrated by reference to reorganisation, with which the author has been associated.

Obviously, the knowledge, experience and effort which can build up a new business are also capable of reviving and re-establishing an old business and there is no reason why an old-established concern with a sound reputation should be allowed to fail if the reorganisation be properly handled and taken in time. In the following, the broad reasoning is applicable to many activities, but for the sake of clearness and continuity the illustrations are limited to automobile production.

In the early days of the Industry, motor cars were a luxury and price was not a main consideration, the output was limited and therefore the original factories were very small. Old-established concerns in Europe have grown in a haphazard way, buildings and plants being increased from time to time to meet the requirements

of growing business and to suit wartime conditions. The result is that at the present time many existing old concerns are a mixed-up collection of different type buildings laid out on no co-ordinated scheme, and equipped with an heterogeneous collection of plant of many mixed types and ages. Most probably the entity represents the ideas of many managements, each of which has no doubt had restricted opportunities. The overall efficiency is usually very low ; therefore, many concerns are either in difficulties, have passed out of business, or passed into the hands of more successful competitors.

Quite a number of firms in Europe are tackling the problem with varying degrees of success. The main factor is, of course, one of finance, for very little can be done in the way of rejuvenating a business unless there is financial backing. Usually the operations in Europe are not of the same spectacular proportions as in the U.S.A., and successful planning and organising on a small scale always present more difficulties than large scale operations. A great fault in the past has been the production of too many models by each concern. It is now recognised that it is impossible to do this efficiently on a small scale, and it is of primary importance to decide on one class of vehicle for production in one factory and limit the number of variations of same. The care and foresightedness with which the choice is made and the efficiency of the design for performance, operation and production will ultimately decide the success or failure of the firm. What type of vehicle should be produced by a given concern is decided by the public's requirements, also the financial standing of the company, its reputation and resources available in the way of buildings and plant, etc.

In the first example to which the author refers, the firm was one of the pioneers of the industry, had built up a solid reputation, and had had a remarkably successful career. It was in a very sound financial position, but the directorate and management recognised the changes taking place in the industry and decided to reorganise and modernise before being forced to do so. In the early stages of the reorganisation, a conservative policy was decided upon and the new programme arranged for the production in limited quantities of one model car in keeping with the firm's past reputation, but with the idea of continuous periodic expansion if sales proved that the right model was being produced. This necessitated an elastic type of layout and organisation which would permit of limited change of product, were it found advisable before a large production programme was undertaken. The firm were, however, definitely committed to the manufacture of a medium-powered, high-class vehicle and the layout, plant, labour, etc., were planned and organised to that end.

The possibilities of producing other vehicles at a future date were well considered, but widely different models would not be

produced on the same layout. The author considers that to attempt to do so would be extremely bad policy and that it is advisable to manufacture different vehicles, such as small cars, large cars and commercials in separate factories, as entirely different sets of conditions are involved, and the plant, labour, organisation and details of layout should be different for each case.

The number of buildings and sub-divisions in the particular works under consideration made an efficient layout impossible.

The number of separate buildings also made supervision a most difficult problem. As it is necessary to have some space in which to commence a re-arrangement of plant for a new layout, and as extensions were required, a new site was acquired and a new works was built and equipped on modern lines for chassis production. Had an attempt been made to re-model the old works before a part of the new extensions were ready, it would have meant closing down altogether for a long period, owing to the congested condition and structural alterations required being drastic. Furthermore, closing down would have entailed loosing the men and staff, also markets would have been lost and no profits made, whilst the policy adopted permitted production and sales to continue which, within a short time wiped off the cost of the new works. The ultimate result is that the company now has modern works equipped with modern plant; the whole concern has four to five times its former production capacity, with possibilities of further expansion, and able to produce better work, more efficiently and cheaper.

In the reorganisation and layout, the author attempted to approach as near as conditions would permit what he considers to be the ideal layout for this class of manufacture. The type of layout will probably be suitable for from ten to twenty years to come, by which time the author thinks that manufacture and production will be an entirely different proposition from what it is to-day.

The fundamental principle of this layout is a continuous onward flow, the raw material being received at a suitable place. It then passes forward to foundries, press shops, sawmills, etc., for primary working, then on to machine shops and assembly, and finally issues at the far end as a completed article. This underlying principle can be applied to any form of production and to large or small numbers; it is merely a question of common-sense how far one can go in applying the principles to a given case. Actually the raw material reception can be a dock, railway sidings or merely a suitable street entrance, according to the magnitude of the scheme. The same remarks apply to the foundries, etc., for, in Europe, most firms purchase their material in a semi-manufactured state. In the case under review the semi-raw material stage becomes receiving quays and semi-raw material stores. In the ideal scheme, the main assembly aisle passes through the centre of the site and the

unit assemblies converge upon this line.

Two main types of buildings are standardised, both being of the ground floor north lighted variety, a heavy type being standardised for the machine and sub-assembly shops, and a lighter type for the body shops, stock rooms, offices, etc. The power plant buildings and foundries, etc., will require a different type structure. The only permanent parts of the buildings are the steel work, floors and roofs; all walls are only temporary and must be easily removable for extensions and alterations. This applies to all internal structures and subdivisions. All stores partitioning, office panelling, etc., should be standardised and easily mounted and dismounted to permit of extensions which can be carried out as required. Standardisation should be carried to what, at present may be considered extremes, and no permanent fixtures, etc., permitted unless absolutely essential. The main idea should be to have a clear bare hall with clear floor upon which the machine tools, assembly tracks, etc., can be set up and moved about as changes and extensions demand. No partitioning or sub-divisions which obstruct the view should be permitted. For vast productions, an overhead road has successfully been employed, connecting with the raw material docks and passing over the entire length of the factory, with branch roads at right angles to various points, as required for distribution of supplies.

The semi-raw material, such as castings or stampings, etc., is either purchased outside or supplied from other works under the control of the company. It is delivered at the quay and passes into the raw material stores from where it is issued into the machine shop, along main supply gangways. The machines are laid across the shop at right angles to the main chassis assembly lines and the assembly of the main units takes place amongst the machines and immediately follows in the finish machining of the main component. The unit assembly lines are so arranged that the finished units arrive in approximately the correct place for assembly to the main chassis assembly lines which run down the entire length of one side of the shop. The completed chassis leaves at the exit at opposite end of shop and passes to the running sheds from where it is driven to the now remodelled old works for assembly of the coachwork and painting, etc. The details of chassis layout have already been made public so will not be here recapitulated.

In the original layout for the body works the line system is maintained, for the chassis enter the factory at one end and leave as completed cars at the other end of the shop. Timber enters, and waste and scrap leave, at the north gate; finished material such as glass, leather, upholstery material, etc., enters at the south gate and are delivered to stores; chassis also enter at the south gate and finished cars leave at this entrance. It is also used for the entry of cars for repairs, etc., and the offices are adjacent.

The seasoned timber passes direct from the stores into the woodworking machines shop from where the timber details pass into another stores. They are issued in sets to detail assemblers who are located outside the stores, and these men assemble the sections such as doors, window frames, etc., on special fixtures. These subassemblies are passed across to the final assembly of the wooden body frame, which is carried out on wheeled tracks, the top surface of which is a replica of the actual chassis frame.

The completed wooden body frame is lifted from the truck by pulley-blocks carried on an overhead runway which extends over the lines of chassis awaiting bodies; the truck itself then passes back to the assembly line for another wooden frame to be built upon it. When the chassis enter the shop the metal workers fit the wings, running boards, etc., prior to the chassis entering the body assembly lines. Several assembly lines are provided so that various types of bodywork can be assembled at the same time. The leather work, upholstery, etc., is prepared at a point (adjacent to the receiving stores) from which it is passed across to the body assembly lines, each body being finished off on its own chassis. The chassis complete with coachwork then passes on for painting by the Duco cellulose process, thence to body finishing and final cleaning and leaves the factory at the south gate.

As alterations have advanced and production requirements increased, the bodies are now built as complete units apart from chassis.

Now as to what can be done in the way of modernising an old factory. The buildings to south of the river were ground floor type structures and of later date than the buildings to north of river; they were utilised for repair purposes without much alteration. The buildings to north of river presented the greatest difficulties and were converted a little at a time. First of all the small surrounding buildings were demolished following which the structures between the two main factories were demolished and the buildings which were ground floor type in fair condition were connected with a new ground floor structure. This gave a good open building and enabled the coachwork programme to be started. The next step was to demolish the old-fashioned multi-storey stone block of offices and buildings which are now replaced by modern type steel structure north lighted buildings.

So much pulling down and rebuilding no doubt appears to be a very expensive alteration, but actually was not so, for the materials salved from the razed buildings paid for the demolitions and practically the only building expenses were for the erection of new portions. The buildings were made the same construction as the new chassis works so as to extend the standardisation. The old heating and fire sprinklers systems were temporarily retained, but additional heating for the timber preparation was obtained from

a waste destructor operating a boiler built adjacent to the machine shop. For the present the original lavatories and canteen have been retained, for money has only been spent on productive works; the old accessories being painted up and repaired. Modern lighting and electrical equipment have also been installed. Prior to the removal of the plant from the old works to the new, the whole change had been planned out and completely operated so that the results that would be obtained were actually known before any change had been made. In the re-operating, a lot of the old machinery was rejected and a large amount of new plant and equipment installed; the car was also completely re-jigged and tooled up. Actual costs came within the estimated figures with a very small percentage of error, the total production times for the whole chassis varying from the estimates by only a few hours. Further extensions for greater production and permitting more intensive application of the line system are already planned and partly underway.

The car for which this layout was prepared was a 15.9-h.p. 4-speed, 4-wheel brake Weymann saloon and when I gave my paper on Efficient Production in 1927 before the Birmingham Section of your Institution, I was asked to supply figures showing actual results obtained. At that time, I was not prepared to make them public as it would not have been fair to my company. As we have now advanced, I propose this evening to quote figures for twelve months back, but wish to make quite clear that they refer to the original layouts as described this evening. The present day figures for greater production are much more efficient. The author is only interested in overall efficiency, and detail efficiency interests me only in so far as it contributes to the final results. Many firms will put forward their total piece-work prices and presumed costs, etc., but it is very rare that they are of much real value, because there is such a lot of contributary detail omitted or undisclosed.

To permit comparisons to be made, I quote the theoretical production times which I consider to be reasonable for the comparatively small production, plant used and type of labour, etc., employed, also lower Continental rate of wages.

It will be seen that 81 per cent. obtained for applied labour is very high and the co-efficient of 56.6 per cent. as the relation between theoretical applied labour and the total labour productive and non-productive, plus all wastage and inefficiencies is remarkably good. About the same date, the co-efficients for bodywork were evaluated and were 74.8 per cent. for applied labour and 58 per cent. overall including administration non-productive, etc. The 56.6 per cent. for chassis and 58 per cent. for bodywork includes every person on the ground from managing director downward up to sales, but does not include any salesmen or sales staff as the author considers production, sales and distribution to be two

TABLE 1.—LAYOUT LABOUR TIMES FOR MANUFACTURE OF ONE CHASSIS.

Unit.	Machining. Floor to Floor Time.	Machining. Set up.	Heat Treatm't and Sandblast	Polish'g etc.	Disc Grind Fettle.	Plating	Tins'th Press Sheet Steel Working.	Assem'y.	Total.
	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
Engine	49 59	41	2 16	50	25	58	5 15	18 33	78 57
Gear Box	25 7	43	1 22	10	5	9	12	6 40	34 28
Rear Axle	42 16	1 7	1 17	—	4	6	2 15	6 5	53 10
Steering	7 52	18	19	43	7	58	6	5	15 23
Front Axle	17 18	19	16	—	—	—	1 6	2 50	21 49
Chassis	15 10	15	34	1 11	22	43	28 40	15 55	62 50
Total	157 42	+3 23							
	161 h. 5 m.		6 4	2 54	1 3	2 54	37 34	55 3	266 37

The figures quoted in Table I are applied labour only, to which must be added inspection, toolroom, labourers, test bed and road test, clerks, foremen and administration and in fact, all contributory labour up to sales. It will, of course, be understood, that for small production these figures are comparatively high and, as production increases, the ratio of administration to applied labour decreases.

The figures given in Table II show the efficiency actually obtained and give the ratio between theoretical layout times, Table I, and actual results covering scrap breakdowns, time men are not at machines and all other wastage. The figures are based on a production of a total of 320 chasiss complete, plus an additional 102 engines and gear boxes.

TABLE 2.

			Theoretical

TABLE 2.

	Number of Days worked. Men Days.	Total number of Hours actually worked.	Theoretical number of Hours required according to Layout.	Coefficient.
Machine Time	7.236 men days.	69.356 hrs.	59.349 hrs.	85.5 per cent.
Heat Treatment, Polish Plate, etc. ...	.624 ,,	5.727 ,,	4.798 ,,	83.8 ,,
Sheet Metal Work...	1.986 ,,	17.723 ,,	12.561 ,,	70.9 ,,
Assembly ... Engine	1.230 ,,	10.422 ,,	7.807 ,,	75 ,,
Assembly ... Gear Box, Steering, Rear Axle ...	.906 ,,	8.305 ,,	6.360 ,,	76.6 ,,
Assembly ... Chassis, Front Axle ...	.798 ,,	7.972 ,,	6.000 ,,	75.2 ,,
	12.780 men days.	119.505 hrs.	96.875 hrs.	81.0 per cent. average for all productive or applied labour.
Non-productive: Inspection	.756 ,,	7.668 ,,		
Non-productive: Toolroom	1.392 ,,	12.784 ,,		
Non-productive: Repairs, etc. ...	1.236 ,,	14.118 ,,		
Non-productive: Test Beds	.216 ,,	1.876 ,,		
Non-productive: Administration ...	.552 ,,	5.772 ,,		
Non-productive: Divers, includes millwrights, carpenters, labourers, boys, door keepers and all incidental labour ...	1.014 ,,	9.508 ,,		
	17.946 men days.	171.231 hrs.	96.875 hrs.	56.6 per cent.

entirely different problems requiring different attributes and mentality.

In conclusion, the author would state it as his opinion that we are now entering on a phase of evolution in which scientific production with its attendant organisation, etc., will play a great part in the near future. Supremacy will lie with the nation and firms which most rapidly assimilate the new theories and science of production and keeps abreast of the advancement by modernising their old factories, their organisation and layout and installing new machinery and plant on a rational scale and in keeping with their production programme. Of one thing the author is convinced, and that is in the past policy of most firms with which he had been associated not a sufficient proportion of profits has been put back into the concerns to keep them up-to-date. His own opinion is that advancement in the automobile business is so rapid that the financial programme should be so devised that the whole plant can be wiped out and replaced within ten years and a proportionally shorter time if two or more shifts be worked. If the plant be operated to capacity, it will be found that its condition will be such that it then cannot compete with new plants and the advancement in design for operation and production which will have occurred in the intervening period.

Discussion.

THE CHAIRMAN (MR. E. C. GORDON ENGLAND) asked the author for further information as to the actual results he had obtained by the overhead delivery of materials. There was a good deal to be said for that method. Another interesting point brought out in the paper was that no partitions were used. That meant, apparently, that there were no detail stores otherwise he could not conceive stores without partitions. As regards the grouping of automatics there was another line which might be explored, viz., delivering all the production from the automatics direct into the stores. That was a practice followed in many American factories and also some British factories. Could the author give any idea of the reduction of inventories as the result of using line production and some idea of the savings by the adoption of this method. An important point mentioned by the author was that not enough of the profits are put back into the business to act as a reserve for new plant and machinery. That applied with great truth in this country and he often felt that production engineers could do a great deal for themselves and their firms if they insisted that they were not satisfied with their machinery and equipment and that it should be kept up-to-date. That was a point which should be kept in front of directors and particularly the finance directors. One point, however, which was a very difficult one at the present time in this country was the very inadequate allowance made by

way of income-tax relief in respect of reserve funds for new plant and machinery. To allow 10 per cent., 5 per cent., or 7½ per cent. as the writing-off value of plant was ridiculous and it was a point which should be impressed in political circles. The fear seemed to be that if larger allowances were made the money would not be used for the specific purposes, but there was no difficulty in overcoming that risk. As things stood at present, however, we could not keep our plant and equipment up-to-date and therefore could not compete with the foreigners.

MR. TAYLOR said he had not been able to practice overhead delivery to the full extent in the Hotchkiss case, but there was little doubt that it had great advantages as could be seen from the manner in which it was practised in the States. He was, however, using a great number of overhead runways, and the system would be developed when the scheme reached its more or less final stage. As regards partitions, what he meant was that in some works stores were placed in all manner of positions in a shop, but in the present case there were no stores in the centre of the shop; they were at the sides and therefore were under constant supervision without difficulty. By placing the stores round the sides of a machine shop, in the manner he had shown, it was easy to remove them for extending the line for increased production. He considered the grouping of automatics a good idea for small parts, but he did not agree with it for larger parts in which case the automatics should be lined up provided there was sufficient work to keep the automatic occupied a reasonable part of the time, although not necessarily the full working day.

THE CHAIRMAN: Do you decide what is an economic time for a machine to be working if it is not a whole-time machine?

MR. TAYLOR said he based that on the over-all costs, because he was a big believer in over-all costs. On this basis there was no guesswork about what was the economic time; it was merely a matter of calculation as to which system would pay the best under the particular conditions.

MR. MARSTON asked if, in fixing the depreciation and obsolescence, the author took the machine-hour rate as a basis? There were cases in which a machine occupied a lot of floor space and might only be worked intermittently and there were other cases in which the machine would be worked more or less continuously. How did the author differentiate between the two?

MR. TAYLOR said he again worked on the basis of over-all costs. By taking the over-all cost a price per piece could be arrived at and on that basis depreciation and obsolescence could be worked out.

MR. MARSTON suggested that this must affect the efficiency in a very unfavourable way because in the case of a machine working for only a few hours per day the non-productive charges must be

very much higher than in the case of a machine working more or less continuously.

MR. TAYLOR said it was all related to the purpose for which the machine was put in and whether the scheme was based on a very rapid increase in production. That was why he had stated that according to the conditions so automatics should be grouped or put into line.

A VISITOR speaking with regard to the lay-out of plant on one floor suggested that it was a short-sighted policy to build temporary structures when it was impossible to extend in all directions. Were there not advantages in the multiple-storey building?

MR. TAYLOR replied that the ground floor scheme is the most efficient from every point of view if the space was available. If not, then there was no alternative but the multi-storey building. That was what happened at the Morris works at Coventry, in the lay-out of which he had had something to do. In that case they were forced to the multi-storey building. Generally speaking, however, the transport of a piece along the level required vastly less work than transport from one floor to another. The cost of the multi-storey building was several times that of a one-storey building, the control was easier in a one-floor building and generally the latter was preferable if the land was available. In Paris the conditions were very different from those in this country and that accounted for the fact that the Hotchkiss works consisted of a number of buildings in different places. Labour would not move about in Paris as it would in this country. Therefore, the works had to be planned where the workers were; the workers would not come to the works and this often meant multi-storey buildings where otherwise the one-storey building would be adopted if the works could have been placed more conveniently in another locality.

MR. FERGUSON asked what percentage of juvenile to adult labour there was in the Hotchkiss works and how did the author maintain a supply of labour on mass production. It seemed that there must come a point when the juvenile labour became adult labour and required full wages. How did the author meet that labour problem and provide more juvenile labour to take the place of the labour that had grown up, at the same time find an outlet for the extra adult labour thus provided?

MR. TAYLOR said that there is very little juvenile labour in France. Indeed, that was one of the problems the country was up against. The point of how the problem mentioned was met, however, settled itself by the natural expansion of the works. It was not to be expected that the production would remain stationary and thus there were full opportunities for passing on the one-time juvenile labour to the adult class at full wages.

MR. FERGUSON said his point was that there must come a time

when it was impossible to absorb more skilled or semi-skilled labour. What happened then ?

MR. TAYLOR said that time had not yet arrived in the particular case he had described and he repeated that if they produced and distributed efficiently that problem settled itself. There had been no trouble with it yet in England.

A VISITOR suggested that Mr. Taylor had solved the problem for himself in England by leaving the Morris works and going over to a new works ! All the same, he felt the problem was there.

MR. GERARD SMITH referring to the question of the one-storey versus the multi-storey building suggested that the disadvantages of the latter were not so great as might at first be imagined. It was obviously necessary to have power to carry material or goods to the top of a multi-storey building, but it would all come down again by gravity to the bottom. After all, there was always the cost of moving stuff about on the floor level, lifting trucks and platforms will avoid the loss of energy in lifting goods from the floor and should always be used. Nothing should ever rest on the floor itself. In connection with line production, one difficulty was heat treatment because this usually upset the line arrangement. In automobile work it was seldom that a heat treated part did not have to be machined again and then it became a moot point as to whether it was better to take the heat treatment out of line altogether or to keep the heat treatment truly in line.

MR. TAYLOR reiterated that he felt the ideal system is to keep everything on one floor with, of course, suitable arrangements for keeping the parts on the moving platform. As to heat treatment, it was all a question of the size of the output. With 2,000 parts per week he would certainly endeavour to get the heat treatment into line. The ideal heat treatment was electrical, but it was expensive owing to the cost of current in this country and therefore—to again refer to the Morris works—what was done was to adopt oil firing and do the heat treatment in the basement with lifts running down. It cost more per piece to send down to the basement, but when the capital cost of electrical plant was taken into account the final cost was less and the over-all efficiency was greater. It was a common practice in the States to use electric heating and to put the heat treatment in line, but the cost of current was against that in this country. However, with large enough production it could be done.

MR. WINN raised the question as to whether it would be advisable to put automatics into line if they were working, say, 30 per cent. or 50 per cent. of their time. Also, how was the labour problem dealt with. What did the men who had been working on the automatics do when there was no work for these machines ? As to the multi-storey building there were instances in which this had been used to great advantage, although possibly in automobile work it

was not ideal. In many other branches of industry, however, it was used very successfully.

MR. TAYLOR said there was no point in putting automatics in line when they were not working for any great length of time during the day. He agreed that there were certain industries where the multi-storey building was an advantage, but for automobile work he preferred the single storey building every time if the land was available. As to handling the labour used on automatics which were not required to operate the full working day, the lay-out must be to have other similar paid work for these workpeople to go to.

A SPEAKER asked as to the labour conditions in England which will not allow a driller to work another type of machine

MR. TAYLOR said he knew nothing about that and he had transferred men from one machine to another in this country without any difficulty. His policy was never to lay a man off, but always to find him another job.

MR. FERGUSON again raised the point as to the risk of getting surplus skilled or semi-skilled labour as the younger workers grow up and develop. Again, what sort of a reservoir of labour had the author to draw on to make allowance for men being ill or losing time ?

MR. TAYLOR said the difficulty of a surplus amount of skilled or semi-skilled labour in the Hotchkiss works had taken care of itself by the fact that the output had gone up four or five times since the scheme was first planned. Actually, the firm was looking round for more labour. The difficulty of men losing time was met with by arranging for a slight buffer in the line.

MR. MANTELL raised the question of arranging the output to meet possible demands so as not to have over-production or under-production.

MR. TAYLOR said that in all business a broad view must be taken and it was the function of the directorate to gauge the possibilities of the particular market and take such risks as must always be taken in business.

MR. MARSTON, reverting to the labour problem in mass production works, expressed the view that the trouble that had been indicated, viz., that a time would come when there would be too many skilled hands, would arise eventually.

MR. TAYLOR said the point that seemed to be overlooked was that the output of a firm must grow if the firm was to keep in business and the difficulty in question solved itself in that way.

MR. MARSTON also raised the question of the best method of payment and asked whether ultimately, by the process of moving men about the shop from one machine to another as had been suggested by the author, we should come to a flat rate of payment.

MR. TAYLOR said his ideal would be a flat rate and a bonus, because there must always be an incentive to get the best out of

the workers. There might be a gradual development towards that.

Answering further questions, MR. TAYLOR said the one thing to be remembered in production was that we must produce to absorb. Ninety per cent. of the production of any country was absorbed by the producers and therefore the greater the production the higher must be the earnings of the producers in order that they might absorb. History had shown that larger production meant higher earnings and in that way the problem of distribution and absorption was as important as that of production.

MR. STANTON said the suggestion seemed to have been made that we shall gradually get to the same level of wages being paid to all classes of workers in one particular shop or factory. He was rather interested in that because there existed at the present time the curious trade union rule that an engineer should get 1s. 2½d. per hour, whilst a coach trimmer received 1s. 7d. or 1s. 8d., yet there were those who held that the engineer was the more skilled man, and had had to serve a longer apprenticeship. It seemed to him that the time had come when the skilled men in a factory, whether they be engineers, trimmers or anything else, should get the same rate.

MR. TAYLOR expressed the view that when we get a little more settled industrial conditions in this country such matters as that will solve themselves. It was all a question of supply and demand.

THE CHAIRMAN: But do you think there should be a uniform rate in a factory whatever the operation being performed?

MR. TAYLOR: No.

MR. STANTON said his point was that at present the engineer, whom he regarded as the more skilled man, received less than the trimmer.

MR. FERGUSON said the difficulty was that immediately the engineer's rate was increased the trimmer would say that he had been in the habit of receiving 5d. per hour more than the engineer and he would still want 5d. more than the engineer, whatever the rate for the latter might be fixed at. That disparity was leading to a shortage of juveniles in the engineering industry.

MR. TAYLOR said there was a shortage of youngsters in the engineering trade at the present time, but that should be an incentive to greater production because the fewer people would get more for the work they did. At the same time, he strongly held the view that these things settle themselves in the long run. The same problems had been faced in the States, but they had settled themselves.

THE CHAIRMAN asked the author if he thought the trend in modern factory organisation is to abolish the demarcation between labour almost entirely and to produce a staff which was sufficiently mobile to be capable of being moved from one operation to another. Did

the author think there was danger in that or would it be the salvation of industry from the point of view of large production ?

MR. TAYLOR replied that he saw no danger in that tendency, but rather salvation. It was very much what had happened in America when Ford found himself short of skilled labour. He immediately set about introducing more semi-automatic and automatic machinery and imported labour from the mid-European countries so that he was able to get along with a smaller number of skilled people and a large quantity of unskilled labour. Gradually the unskilled became semi-skilled and then skilled and were promoted, and that was the process that must go on and, indeed, was going on at the moment. Indeed, he visualised that in time the actual production operations would be fully automatic, with only one or two men overlooking a large number of machines, but there would be a larger number of skilled and semi-skilled workers engaged in preparing the raw material for the final production operations, such as jig and tool makers, gauge makers, machine tool makers and so on. He regarded industry as on the threshold of a completely new development in that respect.

THE CHAIRMAN, proposing a hearty vote of thanks to the author, said there were two outstanding points from the paper. One was that the author had proved in his own experience that the same principles of organisation can be applied to a small production as to a large production. It was seldom we found a man who had been able to accomplish it in both cases and that was a significant fact in the author's case. The other point was the question of where we are getting to in industry, viz., the mechanisation of industry. An illustration of that was an industry which had nothing to do with mechanical engineering ; it was the production of milk in a form suitable for distribution to the public. In this case there was a machine which took crates of dirty milk bottles, washed them, dried them, put milk into them and sealed them, afterwards passing them on to the distribution platform entirely mechanically. Never once from the moment that a dirty crate went into the factory until the clean bottles came out filled with milk, were the bottles touched by hand. The whole process was quite mechanical and it could be seen quite close to London. It was the invention of an Englishman and it illustrated the extent to which we were going in the matter of mechanisation. Something of the same sort happened in the bread industry and that was the tendency all round. It was a thing the author had admirably stressed in urging that the long view must be taken in organising to this end.

The vote of thanks was carried with acclamation and the meeting closed.

THE PRODUCTION AND APPLICATION OF GROUND GEARS.

Paper presented, with cinematograph illustrations, by H. F. L. Orcutt, to a joint meeting of the London Section of the Institution with the Institution of Automobile Engineers, 3rd May, 1929.

Introduction.

THE technique and the design of spur gearing has been exhaustively dealt with in numberless volumes and articles in technical journals. Periodical efforts are still made in freak tooth design hoping it will cure objectionable features which are manifest when the attempt is made to use the spur gear under extreme conditions. It is not realised by many engineers that modern engineering requirements in spur-gear transmission are limited, principally by tooth inaccuracies. In other words, we must look to production methods for the solution of our present-day troubles with spur gears.

Extreme service now called for in gear transmission can be met in every detail by the ground gear.

A brief examination of this service will be made.

First and foremost comes the demand for silence on the roads, in the air, in the workshop, in the home. This demand comes from the public and will force the engineer to make accurate gears. Technical requirements are : Silence, high speed, efficiency, long life, small dimensions, correct velocity-ratios, uniform backlash, heavy load capacity and special tooth designs with valuable attributes, which cannot be executed in cut gearing.

Gear-tooth grinding is sufficiently advanced to prove that the technical demands are almost wholly those of accuracy of tooth finish. This accuracy is limited to variations in tooth form, from 0.0002 in. in small gears to 0.001 in. or 0.002 in. in large gearing. To this accuracy in form must be added indexing accuracy, which is not possible to maintain in ordinary gear-cutting machines. Surface of gear teeth must be highly finished.

It must be admitted that there is but one cutting tool capable of producing tooth surfaces within the above limits, and that is the abrasive wheel.

Finishing of gears with straight spur teeth of uniform quality is now an accomplished fact, and these gears will run at practically

any speed, will run silently with over 99 per cent. efficiency, backlash limits in fractions of thousandths of an inch (if required), they can be made from heat-treated or hardened material, which will stand excessive loads, be of small dimensions and have long life. It only remains for the designer to construct his transmission so that low costs are possible.

(*Examples of various operations were then illustrated by the cinematograph*).

Gear-tooth grinding is intricate and highly technical, the most difficult of all mechanical operations, and very little use of it is made. Its value to industry and widespread application is not yet recognised. It has hardly begun to replace other forms of tooth finishing, which it will surely supersede.

It has not been possible, of course, to show complete details of this process. It is hoped that questions will be asked and criticisms made that will lead to useful discussion.

Visitors wishing to inspect the process shown will be welcomed at the works.

Discussion.

After MAJOR E. G. BEAUMONT had opened the discussion,

MR. GARTSIDE asked if the author would say how he made the formers to get the tone involute shape. Also, taking the end view of the wheel, what was the shape of the diamonds? Was provision made for wear of the diamonds and what relation had their shape to the roller or bowl that ran on the former in the copying arrangement? The difficulty he had been up against in worm grinding was generating the shape of the wheel and grinding a worm which was a straight line on the axial section, through 15 degrees involute. He found that the ordinary commercial diamond with a blunt nose was no use because there was a certain interference, and special diamonds had to be made to tone the wheel on the axis of the work.

THE AUTHOR said that Mr. Gartside had brought out some practical points and one which was not practical when he remarked that formed wheel grinding had not been considered as good as generating. This was no place for controversy, but their experience was that they could get a far greater degree of uniformity with the formed wheel than could be got in the generating system. Probably there were some protagonists of the generating machine at the meeting and he would like them to enter the ring. He thought that grinding against the periphery of a wheel was the correct method of grinding, if accuracy and speed were required. The grinding wheel often was very effective, but it was an extremely difficult operation if one expected to maintain accuracy. With regard to making the forms, this was a process they had developed and about the only process they never showed. All he could say was that the form was developed mechanically to a true involute,

taking off the base circle in the ordinary way. As to the shape of the diamonds, that was a very important point to the grinding man. In many grinding operations, the share of the diamond had not much to do with the grinding, but in this case they used diamonds that had points on them and when these points were reduced too much they discarded them. They usually got diamonds with four or five points on them but sometimes only three. There was a certain limit to the wear of a diamond which you could not go beyond, but the action of the diamond as it went round on the wheel was modified in such a way by the pantograph mechanism that it kept the line through the centre of the diamond as near at right angles to the form it was making as possible, but it was subject to special knowledge and special experience which he did not say they had entirely overcome. Some diamonds had to be discarded very quickly; some would not run a few hours, but others run several months in an astonishing way, and it was a bit of a gamble whether you got a good or a bad diamond. That followed because diamonds were a natural product. With regard to the corner, he took it Mr. Gartside meant the curve at the bottom of the tooth near the flank.

MR. GARTSIDE: No. I mean where the curve runs into the radial line.

THE AUTHOR: That is part of the form.

MR. J. N. HEALD wondered how many people knew what a second of arc was. A friend of his illustrated the difficulty of obtaining such accuracy by saying that a second of arc would be such that if a cannon set up in Trafalgar Square were fired right round the world, and if the variation was not more than the second of an arc, the shot would come back to within 200 feet of the point from which it started.

MR. G. R. MARSH said he would like to congratulate the author on his paper as he knew what he had been through in developing a successful method of grinding gears. Both of them were concerned in this work in 1912 and in those days they thought they had a very good gear if they were within 0.001 in. or thereabouts. As regards the question of diamond wear mentioned by Mr. Gartside, this was a factor which had always interested him because it was quite certain that a diamond would not true up a grinding wheel unless it had a sharp corner and if it had this sharp corner the diamond must wear. Uniform wear must, of course, result in a thicker tooth, while, if the diamonds generating the shape on the grinding wheel did not wear uniformly, the centre line of the grinding wheel would be moved relative to the centre line of the wheel and the tooth would be offset. The author stated in his paper that when using the side of a wheel for grinding, the wheel tended to follow the errors of the gear. This was probably the case where there was a fairly large surface between the grinding wheel and the

gear as when a flat sided wheel was used, but in one process where only the edge of the grinding wheel was used and where there was practically only point contact between the grinding wheel and the work, this tendency to follow the gear errors was almost eliminated. Such a tendency must, naturally, also depend to a large extent upon the grinding wheel itself, as if it is necessary to use a relatively hard grinding wheel in order to maintain a form or shape, then such a wheel would naturally tend to follow errors more readily than a softer and freer cutting grinding wheel, which, due to its shape and the method in which it was used could be chosen purely for its cutting qualities and quite independent of rate of wear. The author had shown in his film the method of grinding shank or stem pinions. These were tapped into a collett by means of a small lead hammer, location being obtained from ball races previously ground on the stem of the pinion, and it seemed to him that the proper method of locating these pinions for grinding was from the same centres which were used when the ball races were being ground. Locating by the method shown in the film seemed conducive to errors of location and he should like to know the degree of accuracy the author obtained. A special sound measuring instrument had also been referred to, and he would like some more information about it. Sound was very difficult to define in regard to quality and quantity and it would appear that the author had devised some means for setting a standard and they would be pleased to hear more about it. The first speaker, Major Beaumont, referred to the ridges in some of the sample gears on view. These were of interest because a ridge running along a tooth parallel to the axis was dangerous in any gear, as, apart from interfering with the uniform angular velocity which they attempted to achieve by grinding gears, it also resulted in shock and heavy intermittent tooth loading. As depicted in the film, the wheel trueing device seemed to be somewhat complicated and he understood that there was a considerable amount of work to be carried out on the formers before they are ready to be placed in the machine. The results Mr. Orcutt secures were good, but this trueing mechanism must require a great deal of attention if the correct tooth form was to be maintained.

THE AUTHOR said that Mr. Marsh knew something about grinding. He was at the author's place many years ago and they exchanged views. He realised that grinding was a big problem, but none of them realised how big it was or what a task there was before them. He thought the diamond was correctly used in the mechanism called the pantograph. When it was worn too much it was quite evident on the gear and the correction had to be made. Special instruments were used by which the diamond was kept to its correct position in the holder which carried it. With regard to grinding on spindles or shank pins, they adopted that partly because of the

type of machine they had, but he thought they should have adopted it in any case because the teeth of the gear must be true with the bearing. They tried to have these bearings ground and finished for the ball races before they received them and grinding from those ball race bearings they obtained results with which there was very little fault to find. In fact, one company for which they ground insisted on having the ball bearings inserted in the gear in which it ran and they ground from the ball bearings, which called for even greater accuracy. The sound instrument was made by the Standard Telephone and Cable Co., in London. It was a mystery to him as to how it worked. It worked by electricity, but he threw up his hands when it came to electricity. There was a pointer which moved round. It was merely an amplifier. It took the vibrations to the amplifier and the amplifier showed you what the noise was, more or less. The ridges which had been referred to were not parallel to the axis. They were the other way about. They rarely got ridges parallel to the axis, in fact, he did not think they got any. The ridges were ripples caused as the wheel passed over the work in the same manner that one saw it in cylindrical work and he did not think grinding would entirely eliminate them. They were more like a chatter mark than anything else and he did not think they had anything to do with the noise of the gear. Of course, there was trouble in keeping gears quiet and that was what they were paid for. The whole thing was a trouble job, but they were eliminating these troubles mechanically as fast as they could and they were also training men to do the work, but he thought it would be a long time before the gear grinding job would be anything but trouble. Indeed, he did not think it would ever be anything else.

Wing-Commander Cave-Browne-Cave, Major Wheeler, and Messrs. A. K. Bruce, M. Platt, W. F. Cully, and H. Glaser having raised various points,

Mr. W. Puckey said that, with regard to the method of making the master form, he did not think the author had said much about the means taken for making it correct. It was, he believed, made eighteen times full size, but it will vary for different gears and there might be some interesting points in that connection. He would also like to know if the author thought it necessary at times to depart from the true involute. He had had experience of cases where it had been necessary to depart from the involute and he was wondering if the author had had any experience of that problem. Also, what was involved in changing from, say, 18 teeth to 16 teeth? It would seem to him that there was quite a lot to do and it rather appeared that the author's machine would compare unfavourably in that respect with some of the other gear grinding machines on the market. Did the author think it necessary to grind the outside diameters of gears? To his mind that had always been a luxury and, of course, when all was said and done, the outside diameter

did not do very much, and as far as he could see it was not necessary to grind it.

THE AUTHOR replied that they kept the original forms, which were eighteen times the size, to within 0.001 in. accuracy. There might be some error during reduction, but it was accounted for by adjustment in the machine. They did not depart from the true involute. They did not endeavour to make freak teeth and always found that the nearer to the true involute the better the gear. The change over from one number of teeth to another was not very formidable. The change over was all right, but the trouble sometimes was to get the gear all right. The change over was quickly done, but it might be found that there was something wrong with the machine which had to be adjusted; no machine was dead accurate. With regard to grinding the outside of the gear, they never used the outside of the gear in any measurements. The measurement was taken on the involute truly developed and they tried to get the correct depth so that the pitch line was correct. They did not require the outside to be finished or ground.

MAJOR WHEELER asked if the gear tooth grinding machine was available for purchase on the market?

THE AUTHOR replied that they did not sell machines because they did not like to sell trouble. Probably they would sell eventually. If a plant could be operated properly without assistance they would not object. They had been eighteen years at this work and realised how far they were from perfection in obtaining a machine that could be put into the hands of an ordinary operator.

MAJOR WHEELER: I understand you are in the position that F. W. Lanchester was in his early days. If we buy a gear grinding machine we want Mr. Orcutt there just as we used to need to have Mr. Lanchester.

MR. METCALFE asked with regard to the method of producing the involute, whether the author would give some indication of how he measured the true involute on both sides in order to secure a balanced tooth, that was, one truly symmetrical about its radial centre and so check for any offset or other inaccuracy that might arise from unequal wear of the diamond points and their associated moving parts?

THE AUTHOR replied that the forms themselves were true involute, as near as they could make them, and that was the basis of all the work. Tests were made to show the errors on the involute all the way from the bottom of the tooth to the top and they got these errors, or tried to, within 0.0002 in. as shown on the indicator. It was quite a simple machine although it looked intricate, but it was almost impossible to explain it. The involute was maintained on both sides of the tooth. The automobile people complain of over-run, but it was pretty hard to find sometimes. You went with a man to see what was happening, but nothing happened and

the man said it was all wrong the last time he was out with the car. However, they test the gears for over-run and in that way both sides were taken care of for automobile work. In other cases it did not matter.

MR. E. D. BALL remarked that there was a machine for spline grinding which he thought was used by the Saurer Company. It was built by them for their own use. They used a small wheel driven hydraulically. A little turbine washer was clamped on the side of the wheel and it was driven by water at a pressure of 400 lbs. per square inch. That machine was used extensively. It ground down both sides of the spline, but it had to be done comparatively slowly, of course.

MR. H. S. LOCKER said he was not able to detect any scientific method of aligning the wheel truly with the blank. Was it a trial and error method? Was there any method of rotating the spindle apart from the indexing mechanism?

THE AUTHOR said that the gear itself was set centrally with the wheel by bringing the wheel into place and lifting it up until it was central. There was also adjustment between the index plate and the gear itself on the spindle by which the gear could be moved a little either way to equalise the cut after it started cutting. That was done by the operator while the cutting was going on.

MR. L. H. HOUNSFIELD (President of the Institution of Automobile Engineers) who occupied the chair, said that he did not want to take part in the discussion. They had been listening to wonderful accuracies, but if they ground to a true involute and the gear remained a true involute whilst the car was unloaded, the moment you load the car, there was not a true involute. The discussion was sufficient evidence of the interest that was taken in this subject. Therefore, he knew they would wish to express their sincere appreciation of the paper and to thank the author for coming there.

The vote of thanks was carried with acclamation.

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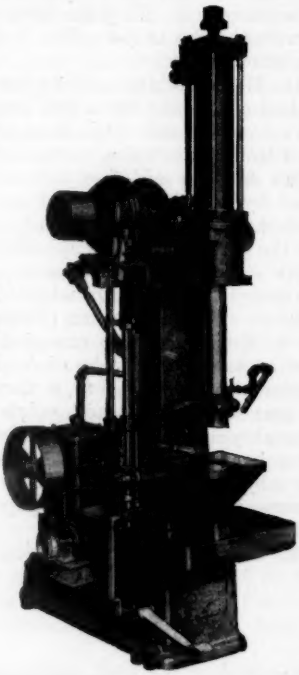

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